



Grounded and Floating Real Inductor Simulations and Experimentations using Second Generation Current Conveyors

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Publication Info

Paper received:
29 May 2016

Revised received:
15 October 2016

Accepted:
01 March 2017

Abstract

Current Conveyors (CC) are active circuit elements which perform analog signal processing. CCs were developed as an alternative to the classical Operational Amplifiers (OPAMP). Unlike OPAMPs, CCs are current-based and they operate according to the principle of 'current conveying' from one terminal to another. As a modified version of the First Generation Current Conveyor (CCI), Second Generation Current Conveyors (CCII) is versatile and useful in designing analog circuits such as filters, amplifiers, inductor simulators etc. In this paper, one grounded and one floating inductor simulator designs are given. These simulator designs are based on CCII's and passive elements like resistors and capacitors. Both inductor simulator designs are lossy and simulate real inductors that have internal resistance. The simulators simulate an inductance in series with an internal resistance. Since inductors are non-ideal, noisy, bulky circuit elements, it is reasonable to simulate their behavior under certain frequency range using CCII's as active elements. In this study, inductor simulators are created first by BJTs & passive elements in SPICE environment and created inductor simulators are tested in a Low Pass Filter (LPF) for a frequency range up to 10MHz. Moreover, both simulators are realized for experimentation using commercially available Analog Device's AD844's which can perform as a CCII & using resistors and capacitors. Realized inductor simulators are tested in the same LPF. The gain of the filter is measured for 15 different frequency values which are located between 10 Hz-10MHz. Finally, both SPICE simulation and experimental results are compared for the same LPF which is constructed using ideal inductor. It is concluded that a lossy, real inductor can be simulated up to certain frequencies by using CCII's both in simulation environment and experiment.

Key words

Second generation current conveyors, inductance simulation, current conveying, analog design

1. INTRODUCTION

1.1. Second Generation Current Conveyors

Second Generation Current Conveyors (CCII) are first proposed as a revised version of First Generation Current Conveyors (CCI) [1]. Compared to CCIs, CCII's are more useful and versatile in analog signal processing implementations such as voltage/current sources, amplifiers, filters, differentiators, integrators and inductance simulations [2]. The main principle of current conveyors is conveying current from one terminal to another terminal.

In Figure 1, block diagram of a CCII is shown. Under ideal conditions, the principle of operation of CCII is as follows:

- If a V_y voltage is applied to the Y terminal, the same amount of voltage will appear at terminal X. Therefore, $V_x = V_y$ will be observed.



Figure 1. CCII Block Diagram

- There is no current flowing into to the Y terminal which makes $i_y = 0$ which is the only difference between CCI and CCII. In CCI, if there is a current flowing into the X terminal, the same amount of current will flow into the Y terminal.
- If there is a current flowing into the X terminal, the same current will also flow into the Z terminal which is $i_x = i_z$.

Under ideal conditions, Y terminal should not draw current from the circuit which means there is infinite impedance at that terminal. Also, since voltage at X terminal follows the voltage at Y terminal, the impedance at X terminal should be very low, ideally zero.

$$\begin{bmatrix} i_y \\ V_x \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_y \\ i_x \\ V_z \end{bmatrix} \quad (1)$$

The matrix which explains the relation between input and output characteristics of CCII in ideal conditions is as shown in (1). In hybrid matrix, ± 1 notation indicates the direction of the current at Z port. If it is +1, then CCII is called as positive type second generation current conveyor (CCII+). If it is -1, that type of CCII is called as negative type second generation current conveyor (CCII-).

1.2. Inductance Simulation

Inductors are non-ideal passive circuit elements. The reasons for their non-ideality are the length of wire to wrap up inductors, the internal resistance of that wire and parasitic capacitance which occurs between parallel wirings [3]. Moreover, inductors are bulky, expensive and noisy circuit elements which contain too much unwanted characteristics [4]. Because of these reasons, physical inductors are not generally preferred in integrated circuits. Instead of physical inductors, 'inductance simulator' circuits are used. Inductance simulator circuits operate like inductors under certain frequency range.

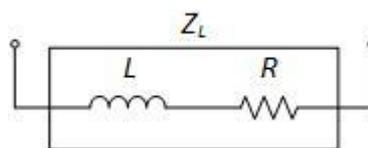


Figure 2. Real Inductor Model

In Figure 2, a real inductor model is shown. In this model, R in series with L is the resistance of the wire used to form inductor. The impedance observed between terminals of a real inductor is given as follow:

$$Z_L = R + sL \quad (2)$$

Using CCII's and certain combination of passive elements like resistors and capacitors, it is possible to simulate both floating and grounded inductors.

2. MATERIALS AND METHODS

One grounded and one floating lossy, real inductor models are given. The proposed models use CCII's and passive circuit elements such as resistors and capacitors as seen in Figure 3 and Figure 9. Those models are tested in test circuits which behave as low pass filter. Also, Analog Device's AD844[5] integrated circuit is

used as CCII+ so that the test circuit is built and measured experimentally. For experimental testing, the gain is measured for 15 different frequency points to compare simulation and experimental results.

2.1. Grounded Inductance Model

In Figure 3, a grounded inductance simulation circuit which consists of one CCII+ and three passive elements is given [6]. This circuit simulates a real inductor which consists of a resistance and an inductor in series with each other. When the impedance is observed from Z_{in} point of view, considering the terminal equations of the CCII+ and passive element characteristics, the Z_{in} is calculated as follows:

$$Z_{in} = Z_1 + Z_2 + \frac{Z_1 Z_2}{Z_3} \tag{3}$$

If Z_1 and Z_2 passive elements are selected as resistors R_1 and R_2 respectively and Z_3 is selected as capacitor C , the following input impedance equation that fulfills the requirement of a real inductor can be obtained:

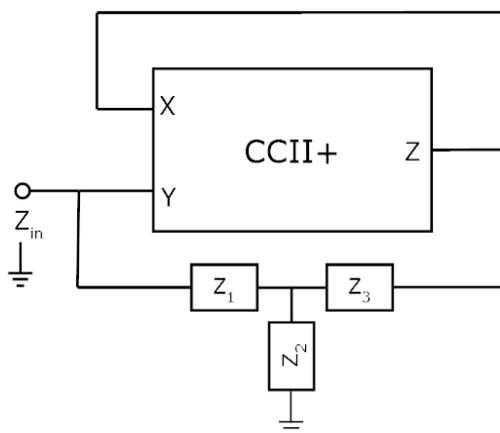


Figure 3. Grounded Inductance Simulator

$$Z_{in} = R_1 + R_2 + sCR_1R_2 = R_{eq} + sL_{eq} \tag{4}$$

Therefore, a lossy (due to the resistance term in the equation) grounded inductance is simulated using one CCII+ with 2 resistors and 1 capacitor.

To model CCII+, Figure 4[7] is used along with NR200N and PR200N SPICE model parameters [8].

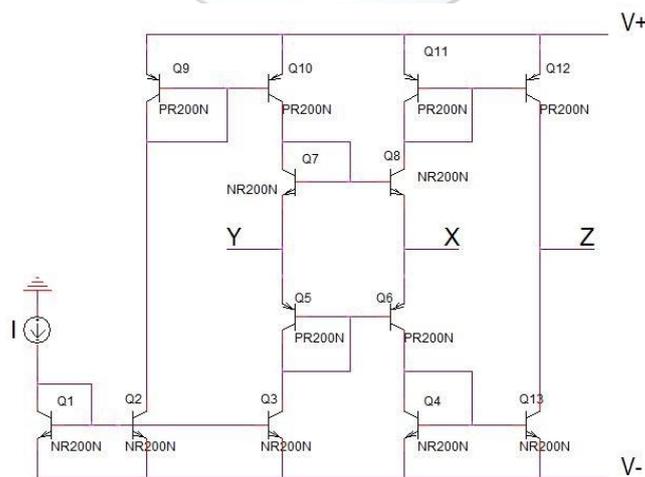


Figure 4. Schematic Implementation of CCII+

2.2. Grounded Inductance Model Experimental Setup

In order to test the suggested inductance model experimentally, an integrated circuit AD844 fabricated by Analog Devices which behave as CCII+ is used as shown in Figure 5. Since it is commercially available,

AD844 is useful in putting simulation level studies into practice. Therefore, experimental results can be obtained.

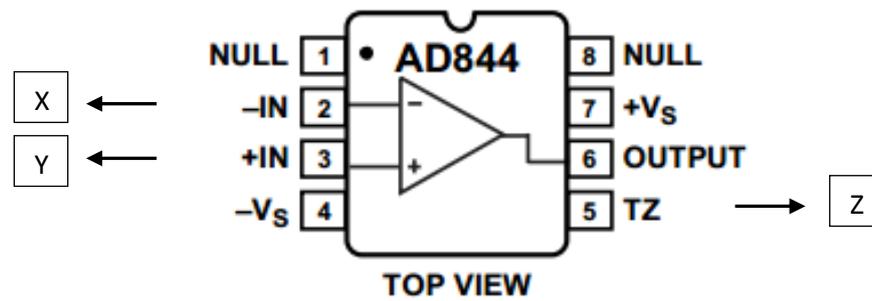


Figure 5. AD844 Block Diagram

For this grounded inductor simulator, if passive element are chosen such that $R_1 = 10 \Omega$, $R_2 = 10 \Omega$ and $C = 10 \mu\text{F}$ then $R_{eq} = 20 \Omega$ and $L_{eq} = 1 \text{ mH}$ is obtained. For the experimental setup, the circuit in Figure 6 is constructed using these resistor and capacitor values.

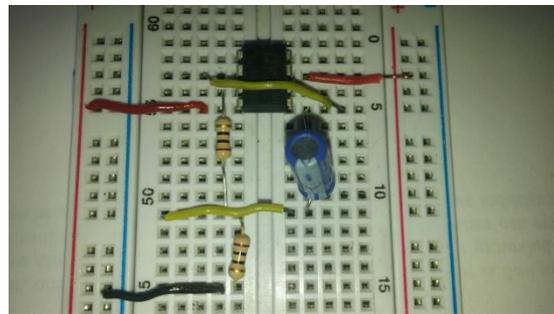


Figure 6. Grounded Inductance Simulator Experimental Setup

2.3. Grounded Inductance Model Test Circuit

We can test this grounded inductance simulator designing a low pass filter as shown in Figure 7.

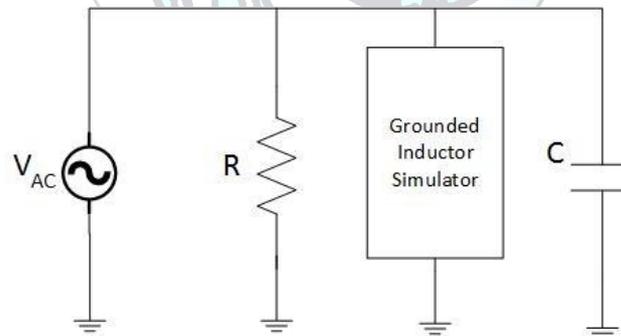


Figure 7. Grounded Inductance Simulator Test Circuit

The frequency response of the test circuit is observed from the current in the grounded inductor simulator point relative to the input current. Three different graphs are obtained as shown in Figure 8. The first graph is the ideal response as if using an ideal inductor in series with a resistor. The second one is simulation results which are obtained in SPICE environment. Second graph is obtained using Figure 4. schematic representation. The third graph is the experimental results. For 15 different frequencies in between 10 Hz-10MHz, experimental results are measured.

From Figure 8, it can be concluded that the cut-off frequency is found at 200 kHz for ideal situation while it is 7 MHz for the SPICE simulation. Experimentally it is found out to be 300 kHz. It is fair to say that SPICE simulated circuit operates very close to the ideal situation until 100 kHz. The experimental circuit can model the lossy inductor up to 40 kHz.

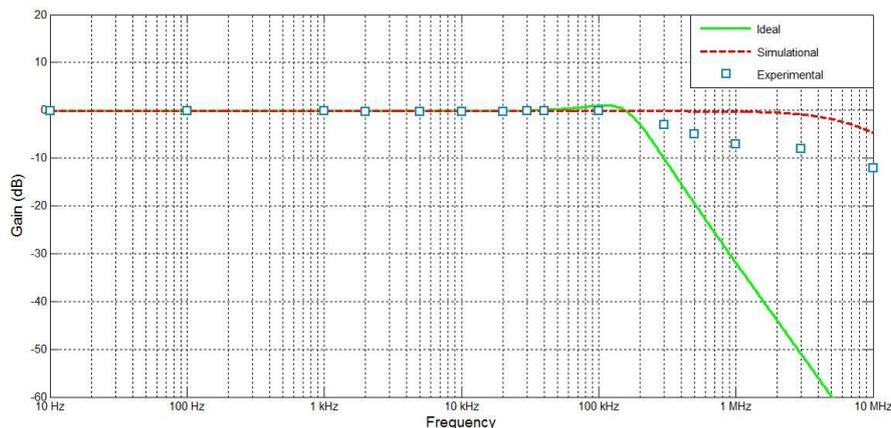


Figure 8. Simulation, Experimentation & Ideal Frequency Responses for Grounded Inductance Simulator

2.4. Floating Inductance Model

In Figure 9, a real/lossy floating inductance simulator that is built with 2 positive-type CCII’s and 3 passive elements is given [9]. If Z_1 and Z_2 are chosen as resistor R and Z_3 is chosen as capacitor C ; the impedance value between the terminals of the floating inductance simulator can be obtained as follows:

$$Z_L = R + sCR^2 \tag{5}$$

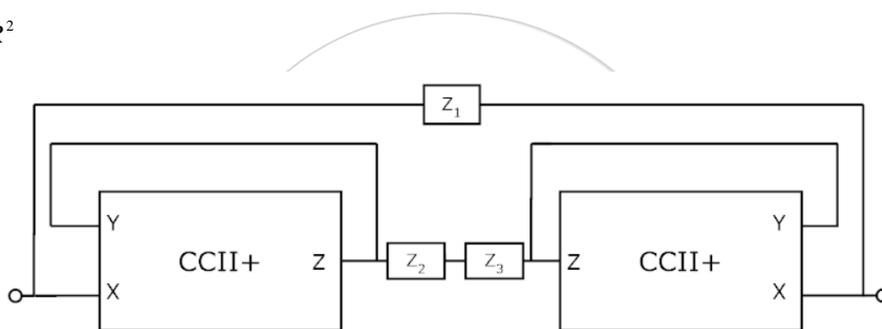


Figure 9. Floating Inductance Simulator

Therefore, the obtained impedance Z_L can model a lossy floating inductor. In order to test the designed floating inductance simulation a PSPICE simulation is run. To model the CCII+’s, NR200N and PR200N SPICE model parameters are used.

2.5. Floating Inductance Model Experimental Setup

For this model, if passive elements are chosen such that $R = 1k \Omega$ and $C = 1 \text{ nF}$; then

$$Z_L = 1000 + s0.001 \Omega \tag{6}$$

impedance value is found. This model simply simulates a 1 mH lossy inductor with 1000 Ω internal resistance. For the experimental setup, the circuit in Figure 10 is constructed using 2 AD844s, 2 1k Ω resistors and one 1 nF capacitor.

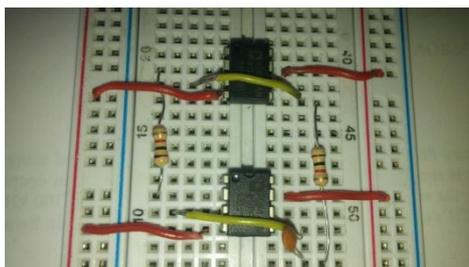


Figure 10. Floating Inductance Simulator Experimental Setup

2.6. Floating Inductance Model Test Circuit

In order to test the floating inductance simulation a test circuit is set as shown in Figure 11.

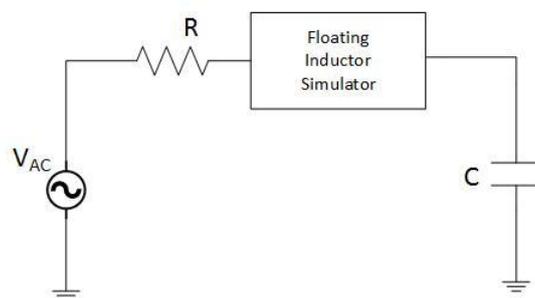


Figure 11. Floating Inductance Simulator Test Circuit

The frequency response of the voltage of capacitor in the test circuit is observed relative to the input voltage. The graphs of ideal, SPICE simulation and experimentation results are shown in Figure 12.

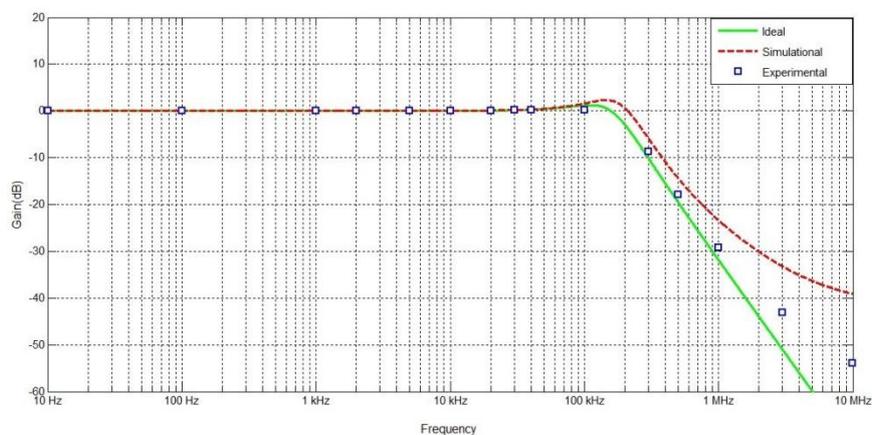


Figure 12. Floating Inductance Simulation, Ideal and Experimental Frequency Responses

In Figure 12, it can be seen that the cut-off frequency is found at 202 kHz for ideal situation while it is 256 kHz for the SPICE simulation. In experiments, the cut-off is found out to be 150 kHz. It can be said that this floating inductor simulator can operate close to the ideal situation up to 90 kHz for the SPICE simulation. Also, experimental results show that the circuit in Figure 11 can operate as if a lossy inductor up to 50 kHz.

3. RESULTS AND DISCUSSION

As a passive electronic circuit element, inductors have many applications. However, using physical inductors in circuit design is somehow problematic due to their size and cost. In order to overcome this issue, instead of physical inductors, inductor simulations could be utilized.

In this paper, two kinds of inductor simulators are given and tested both in simulation and experimentation. Grounded inductor simulator is designed with one CCII+, 2 resistors and 1 capacitor. This design can simulate a lossy inductor such that 1 mH inductance in series with 20 Ω resistance. CCII+ is first modeled by BJTs and simulation results are taken. Also, the same circuit is realized with AD844 and experimental data is obtained. Using the test circuit, the performance of those simulation and experimentation are compared to the ideal response. The simulator can perform up to 100 kHz similar to the ideal response. The experimental results also show that up to 40 kHz realized AD844 circuit can be used instead of a lossy inductor.

Floating inductor simulator is designed 2 CCII+'s, 2 resistors and 1 capacitor. This simulator can simulate an inductor 1 mH with a 1 k Ω internal resistance. The performance of the floating inductor simulator is tested in a test circuit. Simulation and experimentation data is taken and compared to ideal situation. The simulator can perform up to 90 kHz for simulation case and 50 kHz for experimentation very close to the ideal response.

4. CONCLUSION

In this paper, one grounded and one floating inductance simulator is designed and tested using CCII+'s and some passive circuit elements. It is shown that the simulator for grounded inductor can operate like a real inductor up to the 180 kHz, while the simulator for floating inductor can operate up to 100 kHz. With these results, it can be concluded that CCII's can be employed to simulate inductors up to certain frequencies.

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